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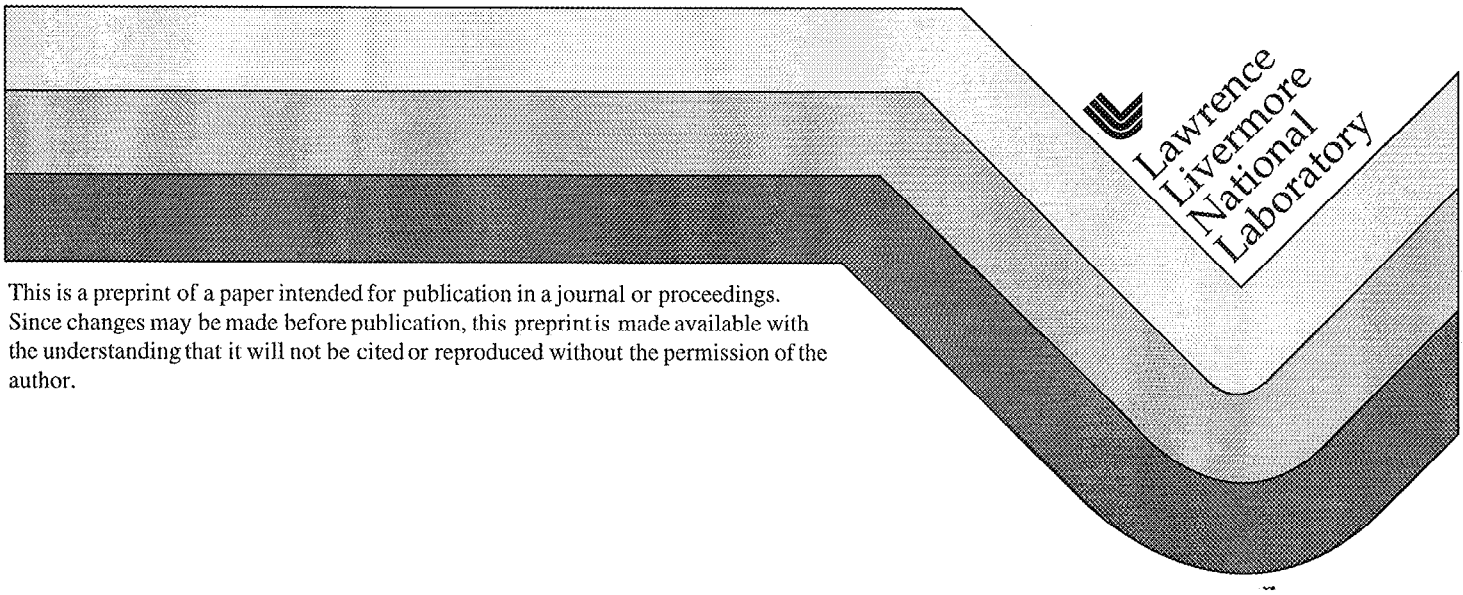

Assuring Safety in the National Ignition Facility[a]

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Introduction

The National Ignition Facility (NIF) is a U.S. Department of Energy inertial confinement laser fusion facility currently under construction at the Lawrence Livermore National Laboratory (LLNL). The NIF mission is to achieve inertial confinement fusion (ICF) ignition, access physical conditions in matter of interest to nuclear weapons physics, provide an above ground simulation capability for nuclear weapons effects testing, contribute to the development of inertial fusion for electrical power production, and to support basic science and technology. To achieve this mission, the facility will require a laser with an output pulse energy of 1.8 MJ and an output pulse power of 500 TW. The laser will be comprised of 192 identical beamlets. Each beam of light will be focused and directed onto a target suspended in the center of the spherical aluminum alloy target chamber. The target chamber will be housed inside a cylindrical, reinforced concrete target bay with 1.8-m thick walls for radiation shielding. This will be located within the Laser and Target Area Building (LTAB), the main experimental building of the NIF. As shown in Figure 1, the LTAB will consist of two laser bays, four capacitor bays, two optical switchyards, a target bay, an attached diagnostics building, a decontamination area, and operational support areas.

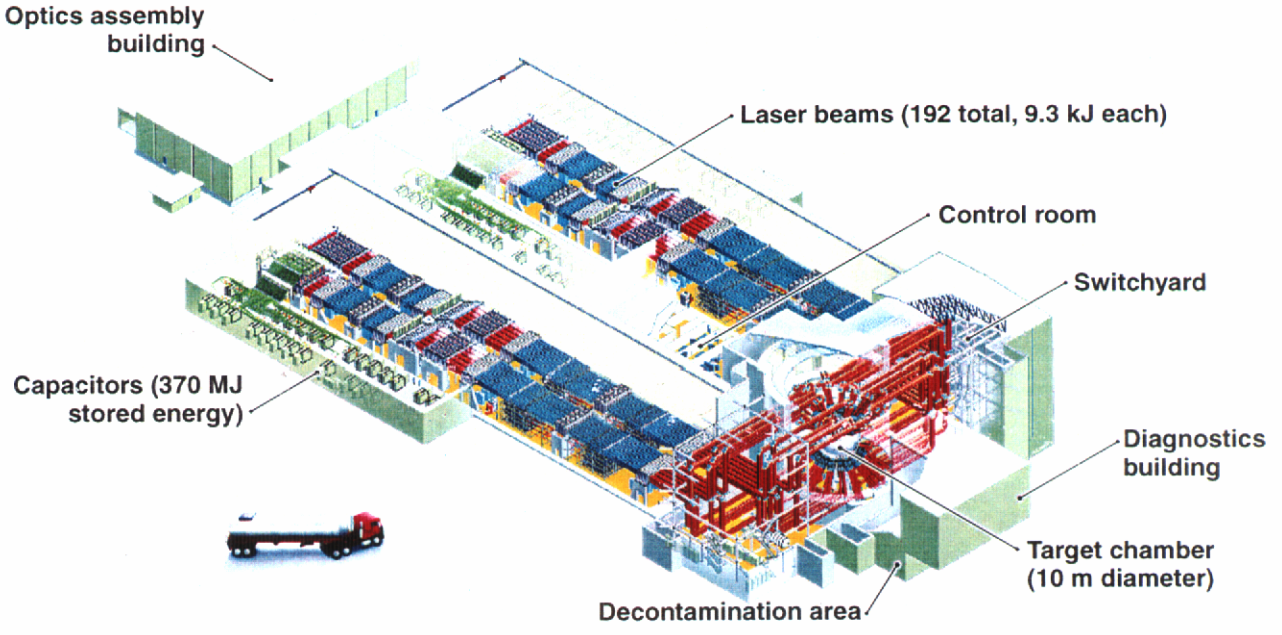

Figure 1: The NIF Laser and Target Area Building

[a] Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Approximately 25% of the 1200 annual experiments will involve tritium and will actually achieve fusion yield, releasing neutrons, x-rays, and debris. Indirect drive targets, which are surrounded by a metal shell that emits x-rays upon laser illumination, will each contain no more than 1.5 Ci (0.15 mg) of tritium. Direct drive targets, which are heated and compressed by direct exposure to laser light, will each contain up to 15 Ci (1.5 mg) of tritium. Unburned tritium will be exhausted from the target chamber to the tritium processing/ collection system. Emitted neutrons will activate the target chamber itself, the supporting structure for the target chamber, the concrete and rebar in the target bay walls, and the gases in the air. Debris from the shot will be retained in the target chamber until clean-up.

NIF construction began in mid-1997. Approximately 225,000 yd^3 of soil were removed from the site during excavation during the summer and fall of that year. Concrete pouring began in December of 1997, and has thus far included the laser bay retaining walls, the target bay floor, and the switchyard floors. This represents almost 10,000 yd^3 of concrete. The largest individual pour was the target bay floor, consisting of 3,400 yd^3, poured over 36 hours. The current state of the NIF construction site is shown in Figure 2.

Figure 2: Current status of the NIF construction site

This paper describes how we have maintained the safety basis during the design process, and how we have assured that safety commitments ultimately are incorporated into the design. The paper also describes our plans for auditing the final, as-built facility against the commitments in the Final Safety Analysis Report (FSAR), which will take place prior to the Operational Readiness Review.

Safety Analysis Process

Safety Analysis Documentation

Safety has been considered from the very early stages of the NIF design. The initial safety analysis document prepared for the NIF was the Preliminary Hazards Analysis (PHA) document (Brereton, 1993), prepared during the conceptual design phase of the Project. This provided an initial identification of the expected hazards at NIF. It also provided documentation of the hazard

classification as low hazard, radiological, on the basis of facility inventories, bounding accidents, and the DOE methodology for hazard classification. As a low hazard, radiological facility, NIF presents minor onsite and negligible offsite impacts. A low hazard facility requires a Safety Analysis Report, and we were directed to prepare this in accordance with DOE Order 5481.1B (DOE, 1986). A Preliminary Safety Analysis Report (PSAR) was prepared, based upon the Title I (preliminary) engineering design. It was approved prior to the start of NIF construction. Since that time, design changes have been reviewed against the PSAR. This review process is discussed later in this paper. The PSAR and change evaluations, along with final as-built design details and operations information are the input to the FSAR preparation process, which is underway at the present time. The FSAR will be completed and approved prior to facility start-up in 2001.

Hazard Identification

The hazard identification process began with a systematic review of planned NIF operations and existing design and safety documentation. Safety documentation prepared for other fusion facilities was also reviewed. This was supplemented by the use of hazard checklists. Additionally, Project personnel were consulted, as were a team of Health and Safety professionals. The result was a comprehensive list of hazards for the construction, start-up, and operation phases.

Based on the identified hazards, potentially hazardous events that could result directly from the energy sources or hazardous materials, or from their interaction, were characterized. This involved consideration of the operational environment, operational activities, facility layout, component interfaces, and performing evaluations to understand interactions and how hazards could harm workers, the public, and the environment.

The unique hazards at the facility consist of laser light, high voltage/electrical hazards, tritium, hazardous chemicals, prompt radiation during shots, and neutron activation of air and structures in the target bay. In addition to hazards encountered during normal operations, nearly 50 accidents that could occur at the facility were identified. Each hazardous event was reviewed to identify potential causes and impacts. Preventive and mitigative features[b] to control the hazards were identified through a review and understanding of the causes and potential impacts of the hazardous events. The events were documented in the PSAR in a hazardous events table. In the approved PSAR, the preventive and mitigative design features listed are commitments that should be incorporated into the design. The process for assuring this is summarized later in this paper.

Change Review Process

A change review process (CRP) was developed to evaluate design and operational changes, or changes in experimental parameters, to determine if their impacts fall within the bounds of approved safety documentation. The CRP was derived from DOE Order 5480.21 (DOE, 1991) and consists of three levels of review or screening. For each change potentially having safety or environmental impacts, an initial screening, called a Level I Review, is performed. Changes screened out at this level should have reasons that are clearly evident such that only a very brief explanation is required. The second level of review employs a screening questionnaire consisting of a series of questions, which explore potential direct, indirect, and secondary impacts of the change. Any change that is not screened out, requires a more detailed evaluation and is transferred to the final level of review. The Level III review is for changes having significant or unknown safety or environmental impacts. At this point, a written evaluation is performed and includes the following:

- a summary description of the change

[b] Preventive design features act to reduce the likelihood of an event occurring; mitigative design features act to reduce the consequences of an event, once it has occurred.

- identification of the safety-related systems or parameters affected by the change
- a discussion of the safety and/or environmental impacts of the change (i.e., response to USQ-like safety evaluation questions), including potential impacts to normal operations
- a conclusion indicating whether or not the change is within bounds of the approved PSAR.

Concurrence from an independent reviewer is required for Level II and III reviews. For evaluations where it is determined that the change would exceed the bounds as documented in the PSAR, Laboratory Management approval is required. DOE will also be requested to concur, thereby accepting the increased risk associated with the change. The completed evaluation will become an addendum to the PSAR.

Safety Feature Audits of Conventional Facilities

Conventional Facilities consists of the building housing the laser experimental equipment, and associated utilities. The Conventional Facilities design of the NIF LTAB was performed by the Architect/Engineering firm Parsons Infrastructure and Technology Group. This was completed early in 1998. Parsons provided input to, and participated in, the preparation of the NIF PSAR. Having the design firm participate in preparing the safety documents ensured early "buy-in" on their behalf. Their participation also clearly established lines of communication and responsibility for the safety commitments contained in the safety documents. Subsequently, during Title II (detailed design), safety features of the NIF LTAB were documented in four construction subcontract packages (CSPs), listed in Table 1. Our safety feature audit of the conventional facility design concentrated on the 100% Title II submittals of these construction documents.

Table 1: Safety Feature Audits Performed for NIF Conventional Facilities

Audit #	Topic	
97-04b	CSP 4	Laser Building Structural Steel, Metal Deck, Metal Sliding and Roof
	CSP 9	Laser Building Buildout, Site and Central Plant
97-04c	CSP 6	Target Area Building Shell
97-04e	CSP 10	Finish Target Area Building

The Audit Process

The NIF Quality Assurance Program Plan (QAPP) addresses the requirements of DOE Order 5700.6C, Quality Assurance (DOE, 1991), for the Project. The QAPP is implemented by procedures contained in the Project Control Manual (LLNL, 1998). NIF Project Procedure 10.1, Independent Assessments (LLNL, 1996), describes the audit process. Figure 3 illustrates the primary steps in the process (planning, auditing and reporting) used in the safety feature audits.

Audit planning consisted of identifying the governing safety documents (NIF PSAR), notifying the organizations to be audited and arranging a schedule, and preparing checklists. Conduct of the audit involved investigation (statusing) of each the checklist items. As a result of investigation the items were sorted into categories (or findings):

- Satisfactory findings
- Good practices - Observation of a significant activity that is exceptionally notable in effectiveness or efficiency, and that may have potential for application to similar types of activities.

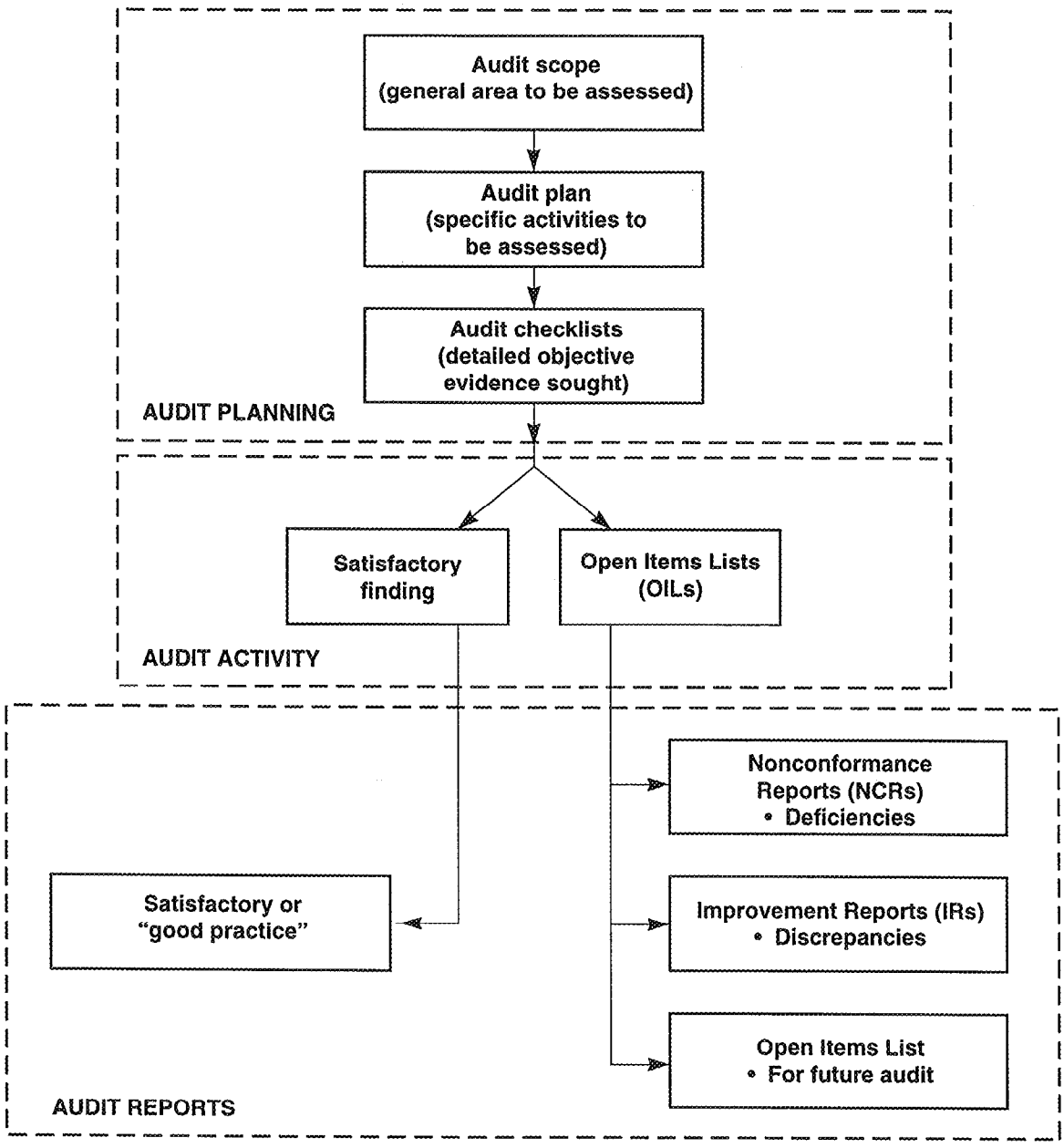

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Figure 3. The Audit Process.

- Deficiencies - A characteristic that renders a product or activity unacceptable or indeterminate; an issue or condition adverse to the required performance. They are documented in Nonconformance Reports.
- Discrepancies - A weakness that degrades performance of a product or activity and signals the need for improvement. They are less serious than deficiencies and are documented in Improvement Reports.
- Open Items - Checklist items that have not been resolved by the time the audit report has been issued to the organization audited. They may also include items found satisfactory,

the audit team wishes to reevaluate in the future. They are documented on an Open Items list.

For the LTAB safety feature audit, checklists containing preventive, mitigative, and other design safety commitments were prepared from the NIF PSAR. These were derived from the hazardous events table described earlier, as well as from the PSAR text itself.

The responsibility for each checklist item was assigned to the design organizations. These assignments were made by the audit team with assistance of the A/E firm. The checklists were divided among the audit team members, and the audit began with a review of design documentation. This included the detailed construction specifications and design drawings. Follow-up meetings were held, as needed, with the NIF and A/E design staffs to verify the location and adequacy of design safety features. Generally, commitments associated with the conventional facility design were within the workscope of the A/E firm and were resolved by the audits. Commitments associated with LTAB special equipment (i.e., the laser and supporting equipment) and/or operations were assigned to NIF Special Equipment or NIF Start-up & Operations Engineering and will be verified in future audits. The location in the design documentation of verified safety design features was noted in the audit checklists. The completed checklists, therefore, serve as a record of the audit, and also serve as safety indices to the design, indicating the location of the design safety features in the Title II documents.

Audit Findings and Means of Resolution

The audits indicated that the great majority of required design safety features were incorporated in the submittals. No deficiencies (requiring a Nonconformance Report) were found. The fraction of checklist items requiring action were small (see Table 2). We feel this reflects well upon our decision to involve the A/E firms early in the process of specifying and documenting the required safety features. Further details of the type and number of audit findings from each audit are listed in Table 3. The findings consisted of design discrepancies (triggering Improvement Reports to the responsible party) and design work-in-progress (which are tracked to closure as Open Items). These issues were subsequently followed-up by the NIF Assurance Office and incorporated in the construction documents as revisions or addenda to the 100% submittals.

Table 2: Safety Feature Audit Summary for NIF Conventional Facilities

Audit #	Topic	Percentage of checklist items requiring action
97-04b	CSP 4 CSP 9	4.3 %
97-04c	CSP 6	9.9%
97-04e	CSP 10	2.8 %

Table 3: Safety Feature Audit Findings for NIF Conventional Facilities

	Safety features verified in 100% design submittals			Means of obtaining resolution	
Audit #	Preventive	Mitigative	Other	Improve-ment Reports	Open Items log
97-04b	53	56	46	3	4
97-04c	32	19	13	6	1
97-04e	43	49	45	2	2

Special Equipment Design Review Process

The NIF Project Title II Design Review process is currently underway and is being performed as prescribed by NIF Project Procedure 5.1 (LLNL, 1997). The goal of the design review process is to produce equipment final designs that meet defined design criteria. The design criteria have been developed in a series of tiered requirements documents including: Functional Requirements and Primary Criteria, System Design Requirements (SDR) documents, Sub-System Design Requirements (SSDR) documents, Interface Control Documents (ICD), and the Preliminary Safety Analysis Report (PSAR). Including the PSAR as a design criteria document ensures consistency between equipment design and the safety analysis documented in the PSAR and will also ensure that the final design will be consistent with the FSAR.

Three types of Title II design reviews have been defined:

- 35% (progress) design reviews are informal reviews held with management and interface organizations to ensure the conceptual design is adequately progressing.
- 65% (requirements) design reviews are formal reviews held to ensure that requirements are complete and adequate and that the design meets the requirements. The review comments are collected and tracked to resolution.
- 100% (procurement readiness) design reviews are formal reviews held to ensure the final design meets the requirements, prior review comments are resolved, engineering documentation is complete, and that the design is ready for transition into Title III for procurement, installation, and acceptance testing. 100% design review comments related to procurement, installation, or acceptance testing must be resolved before the activity commences.

Fifty-two 65% and fifty-two 100% Special Equipment design reviews have been scheduled.

As for Conventional Facilities, checklists were developed for Special Equipment to ensure that the design includes the design features committed to in the PSAR. Table 4 is an example of the Special Equipment preventive design features checklist. The checklist identifies the PSAR event (OE-xx, taken from the PSAR hazardous events table), preventive design feature, Special Equipment work breakdown structure number, equipment Lead Engineer, and design status. It is the responsibility of the Lead Engineer to provide the design status during the design review. However, prior to the design review, a team that includes the lead safety analyst and other safety specialists, meets with the Lead Engineer to review the design with respect to safety and PSAR design criteria. If

Table 4. Example of NIF Special Equipment Safety Features Checklist

Event	Preventive Design Feature	WBS	Responsible Engineer	Design Status
OE-21: Accidental exposure to prompt radiation during shot inside target bay	Interlocks to prevent entry to target bay	1.5	B. Reed	NIF-525 *SIS Requirements & Design Description*, LEA96-285501, LEA97-TBD7
OE-41: Loss of Electrical power	Stand-by power	1.5	B. Reed	NIF-525 *SIS Requirements & Design Description* LEA97-TBD5, Delta F Series 500 manual
OE-45: Exposure to Laser Light	Interlocks on laser system	1.5	B. Reed	NIF-525 *SIS Requirements & Design Description*

necessary, design changes needed to bring the design into conformance with the criteria are determined. Table 4 is an example of a completed checklist that was presented during the Safety System 65% design review.

Upon completion of the 100% design review, design documents such as drawings and procurement specifications will be audited in a manner similar to the Conventional Facilities safety feature audits to ensure design features are incorporated into the design.

Future Plans

This paper has described the process used by the NIF Assurance Office to assure that design safety features required by the PSAR are contained in NIF Title II design documents. The process has involved hazard analysis, safety feature specification, design review, and audit of design documentation. Further work is needed to ensure that the facility as-built, incorporates the design safety features so far documented. In addition, during Title III (construction and field engineering) we will be involved in the management of changes to the facility safety requirements and to the design.

We plan to conduct safety audits of the as-built design documentation at the completion of work and to perform site audits of the completed facility (safety walk-downs) prior to beneficial occupancy by the Program. Special Equipment will be procured, inspected, and acceptance tested during Title III. Surveillance will be performed to ensure preventive and mitigative safety features identified during the design process are fabricated as designed and function properly. Subsequently, safety walk-downs and reviews of integrated experimental hardware and software systems will occur prior to, and in support of, the Operational Readiness Review (ORR) for the facility. The ORR is scheduled for 9/01.

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